Antecedents of knowledge sourcing and reuse from a knowledge repository in the virtual product prototyping: the role of knowledge and system quality dimensions

Abstract

Knowledge has been identified as one of the most critical resources for achieving innovation and competitive advantage. Knowledge management systems (KMS) are, therefore, being adopted by companies to enhance knowledge management (KM) processes and innovation. Since most of new products projects are not "clean-sheet" efforts, rather incremental redesigns of existing products, R&D people often retrieve and reuse existing knowledge to solve recurring problems in the prototyping of new products. Thus, knowledge sourcing and reuse are particularly important in this product development process. In the present research we investigated the antecedents of knowledge sourcing and knowledge reuse from an electronic repository. Predictions were tested in the context of the virtual vehicle prototyping process with data from 121 respondents of a large European Automotive supplier of R&D. Results provide support that knowledge accuracy, knowledge format, knowledge completeness are strong predictors of knowledge reuse. While system integration, flexibility, response time are considered strong determinants of knowledge sourcing in KMS. The study develops and tests a new model for measuring KMS success in the context of virtual product prototyping.

Keywords knowledge quality; knowledge reuse; knowledge management systems; system quality; knowledge sourcing; virtual product prototyping; automotive sector.

1. Introduction

Achieving competitive advantage urges firms to acquire, integrate, store, share and apply increasing amounts of knowledge (Grant, 1996, Davenport and Prusak, 1998, Kankanhalli et al., 2005). Businesses during the product development process, develop and archive huge amounts of knowledge on product design, product anomalies, anomalies solution, best practices, and the like. The capability of organisation to enable a rapid and effective sourcing of such knowledge is of critical importance in the product prototype development process. Companies are, therefore, adopting knowledge management systems (KMS) to boost knowledge management processes in sectors such as the automotive industry. However, research has found that the introduction of KMS in organisations often fails (Malhotra, 2004; Chua and Lam, 2005). The reasons for this failure include behavioural and social factors related to their adoption (Malhotra, 2004), or to technological, cultural, knowledge content, and project management aspects related to KMS implementation (Chua and Lam, 2005).

The present study attempts to identify the determinants of KMS success focusing on knowledge management processes post-KMS implementation in the context of the new product development process. Since most of NPD projects are not "clean-sheet" efforts, rather incremental redesigns of existing products (Chandrasegaran *et al.*, 2013), R&D people often source and reuse existing knowledge to solve recurring problems in the design of new products (Filieri and Alguezaui, 2015). The reuse of existing design knowledge is the key to realize rapid product design (Lu *et al.*, 2011). Research has measured IS success in terms of the system capacity to foster users' use (and intention to use) and satisfaction with the system (DeLone and McLean, 1992; Wang and Strong, 1996; Lee *et al.*, 2002; Nelson *et al.*, 2005), and perceived usefulness (Seddon, 1997).

This study specifically examines the processes of knowledge sourcing (KS) and knowledge reuse (KR) in the virtual product prototyping development (VPPD) of vehicles. This is one of the most complex stages of the new product development (NPD) process and research on this

NPD process is currently at an embryonic stage (Vaccaro *et al.*, 2011). Since KMS have been built to contribute to the competitive advantage of companies by supporting and enhancing organisational knowledge (Alavi and Leidner, 2001; Benbya and Belbay, 2005), we attempt to identify the antecedents of two critical knowledge management (KM) processes, namely *sourcing* and *reuse* of knowledge from a KMS.

Drawing on an information systems success model (DeLone and McLean, 1992), we attempt to identify the antecedents of knowledge sourcing and reuse and we hypothesise that the different *system quality dimensions* of a KMS may affect the rapidity and efficiency of knowledge *sourcing*; while *knowledge quality dimensions* may impact on user's frequent and easy *reuse* of knowledge. The study is focused on knowledge repositories, which are a type of KMS. These systems are designed to facilitate knowledge/information search, organisation, storage, and sourcing (Wu and Wang, 2006). Our hypotheses have been tested in a major European automotive R&D centre, also contributing to the literature on KMS in the automotive industry.

This article begins with a summary of the relevant literature relating to KMS, KS, KR, then proceeds with an explanation of the research design and context. The results regarding how knowledge repositories enhance KR and KS in the VPPD are explained and discussed, and finally the academic and managerial implications are reviewed.

2. Literature Review

A KMS is a class of IS created to support KM processes, namely the processes of knowledge creation, storage, sourcing, transfer, and application (Alavi and Leidner, 2001). According to Maier, KMS represent a "networked collections of contextualized data and documents linked to directories of people and skills and provide intelligence to analyse these documents, links employees' interests and behaviour as well as advanced functions for knowledge sharing and collaboration" (Maier, 2007, p.7). KMS is an extension of an organisation and employees' memory and skills since they provide access to past knowledge, which is always available for use and consultation. Organisations use KMS to enable the sharing of the intellectual capital created and owned by knowledge workers in the organisation in order to increase decision making effectiveness and ultimately competitive positioning (Rao and Osei-Bryson, 2007).

There are two broad types of KMS entitled knowledge repositories and expert networks (Sambamurthy and Subramani, 2005; Wu and Wang, 2006; Gray, 2000). Both are designed to improve the ability of employees to search for knowledge and to find knowledgeable individuals within an organisation. Expert networks are networks of individuals identified as experts in some professional area who are electronically accessible by others with questions related to their expertise (King *et al.*, 2002). Knowledge repositories, which form the focus of this study, facilitate knowledge and information search, organisation, storage, and sourcing (Wu and Wang, 2006). Repositories are also known as knowledge maps, and refer "to a straight-forward directory pointing to people, documents, and repositories" (Lai *et al.*, 2009, p. 314). Seemann and Cohen (1997) liken knowledge maps to "corporate yellow pages", showing the repositories of codified knowledge and people's expertise (i.e., their CVs, competency profiles, etc.) under topics rather than departmental headings. In sum, knowledge repositories provide ad hoc technical knowledge for the solution of frequently occurring problems (*know-how*).

Research on KMS is at an embryonic stage (Gray, 2000; Wu and Wang, 2006; Nielsen and Michailova, 2007; Kulkarni *et al.*, 2007; Jennex and Olfman, 2008; Durcikova *et al.*, 2011). Gray (2000) developed a theoretical model in which knowledge repositories and expert maps are argued to improve the variety of knowledge available to problem-solving teams, subsequently improving their analysis of complex problems, which in turn may positively affect effectiveness of the solutions teams generate and the company's adaptability to competitive environment. Wu and Wang (2006) used the DeLone and Mclean (2003) model to measure KMS success, concluding that knowledge quality affects perceived KMS benefits and user satisfaction, while system quality affects user satisfaction only. They also found that perceived KMS benefits affect user satisfaction, and both influence systems' use. Similarly, Kulkarni *et al.* (2007), in a study on 150 knowledge workers, found that knowledge content quality, knowledge system quality and perceived knowledge usefulness positively affect user satisfaction, which was also positively related to knowledge reuse (together with incentives and leadership). Nielsen and Michailova (2007) analysed the organisational factors influencing the design and implementation of distinctive types of KMS in multinationals. Durcikova *et al.* (2011) analysed how KMS affect exploration (solution innovation) and exploitation (solution reuse) practices in the context of technical support work. Their results show that KMS access does not directly determine solution innovation or solution reuse, rather KMS is a moderating factor in the relationship between the organisation's psychological climate for innovation and autonomy and solution reuse and innovation.

Although KMS have been used by companies for facilitating KM processes, no research has been conducted to measure how KMS foster such processes. Since a KMS is expected to contribute to the competitive advantage of companies by supporting and enhancing organisational knowledge (Alavi and Leidner, 2001; Benbya and Belbay, 2005), the present research examines the capacity of KMS for enhancing KM processes. In particular, this research attempts to address the noted deficiency by measuring the strength of the respective relationships between knowledge quality dimensions and knowledge reuse, and between system quality dimensions and knowledge sourcing.

3. The virtual product prototyping process

Cooper (1990) developed a model that divides the innovation process into a seven-stage process, each stage being composed of a group of activities, roles and responsibilities.

The virtual product prototyping is a stage of the new product development process (NPD) that precedes a company's approval of a product concept and anticipates the virtual and physical test of a new product (Cooper, 2008).

In the automotive sector, car manufacturers have recently introduced virtual simulation tools to improve the performance of this process. Virtual simulation software tools (i.e. AutoAssem or the digital mock-up, DMU) are software tools for planning and scheduling of manufacturing activities at workcells or at system level (Xu *et al.*, 2012), are significantly changing the way firms design new products and analyse and resolve technical problems (Dodgson *et al.*, 2007). The virtual product prototype development (VPPD) is where R&D people from different areas of a company work together in a virtual environment to develop solutions for the problems that emerge during the design and assembly of a vehicle's parts. The VPPD is a knowledge-intensive process in which R&D people generate vast amounts of knowledge, such as pictorial, symbolic, linguistic, virtual and algorithmic knowledge (Owen and Horváth, 2002; Chandrasegaran *et al.*, 2013). Such knowledge is stored in knowledge repositories, manuals, technical reports, and so forth (Corallo *et al.*, 2009). Since most of NPD projects are not "clean-sheet" efforts, rather incremental redesigns of existing products (Chandrasegaran *et al.*, 2013), R&D people often retrieve and reuse existing knowledge to solve recurring problems in the design of new products. The reuse of existing design knowledge is the key to realize rapid product design (Lu *et al.*, 2011). However, apart from a recent qualitative study on the design of a virtual vehicle prototype through the DMU (Filieri and Alguezaui, 2015), no research has investigated the antecedents of knowledge sourcing (KS) and knowledge reuse (KR) within the virtual product prototype development (VPPD) in the automotive sector. For instance, it is valuable and current to investigate the determinants of knowledge sourcing and reuse from a repository within the product prototyping process.

4. Theoretical framework

To address the strength of the relationship between knowledge quality dimensions and knowledge reuse, and between system quality dimensions and knowledge sourcing, this research uses a model developed by DeLone and McLean (1992) (see Fig. 1). DeLone and McLean (1992) developed a theoretical model in which information quality and system quality are argued to be important antecedents of IS success. The use of a system and the users' satisfaction is argued to have an individual (behavioural) and an organisational impact. The model postulates that system quality and information quality affect system use and user satisfaction (individual impact), and the latter effect on organisational performance (organisational impact) (DeLone and McLean, 1992). Although the DeLone and McLean's model has been criticised and respecified by some scholars (e.g., Seddon, 1997), its validity has been widely accepted in IS research (Wixom and Watson, 2001; Lee *et al.*, 2002; Shaw, 2002; Rai *et al.*, 2002; DeLone and McLean, 2003; Nelson *et al.*, 2005; Wixom and Todd, 2005; Wu and Wang, 2006).

The DeLone and McLean (1992) model was originally developed for examining the determinants of information system success; however, this model has been also adopted for measuring KMS success (Jennex and Olfman, 2004; Wu and Wang, 2006; Kulkarni *et al.*, 2007). According to Wu and Wang (2006) the information and system quality criteria are equally applicable in measuring KMS success. Filieri and Alguezaui (2015) investigated the barriers and enablers to knowledge sourcing and reuse in the VPP and found that system quality factors such as the poor operational quality of a repository hinder knowledge sourcing, while the poor quality of the codified knowledge and its complexity affect knowledge reuse. This study found that system quality factors affect knowledge sourcing while knowledge quality dimensions affect knowledge reuse. Therefore, in line with these scholars we have decided to adopt the DeLone and McLean's (1992) model to measure the antecedents of knowledge sourcing and reuse. The model assesses the semantic and operational quality of a KMS and is therefore appropriate for the present study in which we argue that the operational quality of a system may enhance KS, while the semantic quality of the knowledge stored into a repository affects its reuse. The semantic quality of the knowledge of a repository is conceptualised as timely, well formatted, accurate, and complete, and is argued to affect the reuse of existing knowledge during the development of a vehicle prototype. The quality of a system, which is determined by it being reliable, flexible, responsive, and integrated, is argued to foster the sourcing of knowledge within a repository.

The elements of the model and their associated hypotheses will now be described.

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3.1 Knowledge reuse

Knowledge reuse refers to the activity of individuals or groups within the firm using knowledge generated by a different individual or group within the same firm in order to be more effective and productive in their work (Alavi and Leidner, 2001). To be effectively accessed and reused, the knowledge needs to be codified correctly and archived properly. Codification is a critical activity for many organisations since it avoids knowledge losses after a project is completed or when the team members move on to other activities (Schindler and Eppler, 2003). When the knowledge seeker locates the knowledge he should be capable of applying it to new projects. This means that knowledge has to be of high quality to be easily and effectively applied to new projects or problems. Knowledge reuse is effective when knowledge seekers frequently apply a piece of knowledge to recurring problems or routinely activities. The frequent reuse of knowledge will increase its economic benefits, since the higher is the number of times knowledge is reused, the higher will be its economic benefits (Kogut and Zander, 1992; Markus, 2001; Gray and Durcikova, 2005). This study investigates the impact of different knowledge quality dimensions on the reuse of technical knowledge developed during problem solving occurring in the virtual prototyping of a vehicle. The next section deals with the knowledge quality dimensions adopted in this study.

3.2 Knowledge Quality

According to DeLone and McLean (1992), information quality measures the semantic success of an IS. In this research, we focus on knowledge quality. Accordingly, knowledge refers to a "fluid mix of framed experiences, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information" (Davenport and Prusak, 1998, p. 5). Knowledge originates within organisations and within the minds of employees and can be embedded into KMS in a codified form. However, the quality of the knowledge archived into a KMS may be an important determinant of KR. Researchers in IS have investigated the antecedents of information quality (IQ) and have produced a plethora of information quality determinants, which has required the creation of sub-dimensions. We have adopted the same dimensions used for measuring information system quality for knowledge because scholars have established that some of the data quality dimensions considered being important to data warehousing and decision support systems can be applicable to knowledge (Rao and Osei-Bryson, 2007). Researchers have distilled over 30 dimensions represented in the literature into four key constructs representing the categories of intrinsic IQ, contextual IQ, and representational IQ (Nelson *et al.*, 2005, Wang and Strong, 1996). Moreover, they have also identified the most frequently used IQ dimensions, which have been adopted in this study to measure knowledge quality, namely accuracy (intrinsic quality), completeness (contextual quality), currency (contextual quality), and format (representational dimension) (Wand and Wang, 1996; Nelson *et al.*, 2005; Rao and Osei-Bryson, 2007). Below we discuss each of the information quality dimensions that have been adapted to measure knowledge quality in this study.

Knowledge accuracy. Information accuracy has been defined as the correctness in the mapping of stored information to the appropriate state in the real world that the information represents (Nelson *et al.*, 2005). In this study, knowledge accuracy is defined by the correctness, unambiguity, meaningfulness, and ease of understanding of knowledge (Nelson *et al.*, 2005). The level of knowledge ambiguity plays a negative influence on knowledge reuse or sharing as established in previous studies at both intra and inter-firm level (Lippman and Rumelt, 1982; Simonin, 1999; Szulanski, 2000; Levin and Cross, 2004; Szulanski *et al.*, 2004). However, when knowledge is clear and meaningful it is easier to understand and to apply to other projects. Therefore:

H1: *The degree of knowledge accuracy is positively related with knowledge reuse.*

Completeness is a contextual dimension of information quality. Knowledge completeness is dependent on a user's informational needs, where information may be perceived as complete for one user and incomplete for another who has different needs (Nelson *et al.*, 2005). Completeness refers to the degree to which all knowledge needs are covered by the knowledge stored in a KMS. In managerial terms, the notion of completeness refers to the degree to which the knowledge for making decisions or completing tasks is entirely sufficient and available for the decision maker's use (Turner and Makhija, 2006). When the knowledge archived into a system is complete, R&D people will reuse it more frequently. Therefore:

H2: *Knowledge completeness is positively associated with knowledge reuse.*

Information *currency* is another contextual predictor of IQ. Currency refers to the fact that information is up to date (Nelson *et al.*, 2005). Knowledge currency may be an important aspect especially in knowledge-intensive industries, where it evolves very rapidly (Chen *et al.*, 2010). Therefore, the degree to which knowledge is up to date, with regard to a specific process (e.g., vehicle irregularities solution), may affect its reuse. Conversely, if knowledge is outdated, it will not be reused to solve problems (e.g., anomalies) which require current knowledge. Thus:

H3: *Knowledge currency is positively associated with knowledge reuse*

Information *format* refers to the degree to which information is presented in a manner that is understandable to the user and thus aids in the completion of a task (Nelson *et al.*, 2005). Many organisations use forms and templates to codify and archive knowledge in order to facilitate its understanding. Knowledge captured in forms is generally well structured and can be easily captured and formalised (Wu, 2009). A standardisation of knowledge representation in forms may facilitate visual recognition and hasten understanding of the codified knowledge. In order to be reusable, knowledge must first be codified and this requires a suitable *form* of representation (Wu, 2009). A knowledge format helps users to immediately locate the knowledge they are looking for in a document. An intelligible format means that knowledge has been stored in such a way that different users can reuse it easily; namely it has a representational consistency (Wang and Strong, 1996). Thus:

H4: *Knowledge format is positively associated with knowledge reuse*.

3.3 Knowledge sourcing

Levitt and March (1988) defined knowledge sourcing as the “extent to which individuals intentionally access other’s expertise, experience, insights and opinions” (Gray and Meister, 2004, p. 821). In this study, we investigate knowledge sourcing from an electronic knowledge repository. *Knowledge sourcing* can be defined as the activity of individuals and groups searching for and accessing the knowledge needed to perform a task from an electronic knowledge repository. *Knowledge repositories* have been created to facilitate users to find out previous solutions to problems, best practices, lessons learnt, and other typologies of knowledge that can be reused by others for performing a specific task. Knowledge repositories are used by companies following a codification strategy with the need to make technical knowledge rapidly available to as many geographically dispersed users as possible. A repository, or knowledge map, is a basic tool for knowledge users to retrieve necessary knowledge and to analyse the relationships between knowledge (Kang *et al.*, 2003).

In the context of the present study, knowledge sourcing from a knowledge repository is a routinised activity occurring during the anomaly identification and solution within the virtual vehicle prototyping. In this process, industrial designers and engineers often access to solutions which have been developed and archived into the repository by other R&D staff. This assists in the solution of complex problems. In this study we are more interested in understanding the factors related to the quality of the repository itself, aiming to investigate how strongly they contribute to the effectiveness of knowledge sourcing.

KMS functions which enable a rapid location and ease of access to the required knowledge are argued to be of critical importance. This implies that the time and energy of a knowledge seeker to locate the needed knowledge may be reduced by the capacity of the system to enhance such activity. Different attributes such as reliability, response time, flexibility, and integration refer to the quality of a knowledge management system. These attributes may positively affect the effectiveness of knowledge sourcing. Below we discuss system quality and its sub-constructs.

3.4 System quality

The focus on system quality is on the desired characteristics of the information system itself, which makes knowledge available to different users. System quality (SQ) measures refer to the operational characteristics of the system and reflect the reliability of the system, independent of the knowledge it contains. SQ measures used for IS can be equally applicable to measuring KMS success (Wu and Wang, 2006). Nelson *et al.*'s (2005) literature review of SQ antecedents suggests that there are five key dimensions, namely accessibility, reliability, flexibility, response time, and integration. This model includes both task and system dimensions. The former cover dimensions such as flexibility and integration, for which an assessment will depend on the specific task and setting investigated (Nelson *et al.*, 2005). The latter are those dimensions, such as reliability and accessibility, which are largely invariant across different uses and can be assessed independent of task, context, or application (Nelson *et al.*, 2005). We have adopted this model for our study and preferred to not include system's accessibility as a construct, because items can be confused with the items used for measuring our dependent variable (knowledge sourcing). Below we explore each dimension in turn.

Reliability refers to the technical availability of a system over time. This construct refers to the frequency with which a system has technical problems, such as bugs, crashes and so on. It also refers to the ability of a system to restore data and malfunctioning to an operational state (Halloran *et al.*, 1978; Shaw, 2002). A system that frequently malfunctions is not perceived as reliable by users who might decide to not use it for knowledge sourcing. Therefore, they might be oriented to search the needed knowledge in other applications or personally via verbal communications. Moreover, if a system is not reliable, this may slow down the sourcing of knowledge and over time users might organise alternative ways to store and to retrieve the knowledge created, for example, using other applications. However, a repository that is reliable over time becomes a daily support to workers of different departments and business units. Therefore:

H5: *The reliability of a KM system is positively associated with knowledge sourcing*

Response time refers to the time needed by a system to provide an answer or to perform an action to a user's request (Nelson *et al.*, 2005). The response time of a repository may be an important determinant of SQ in the context under investigation. In fact, knowledge-intensive industries, such as the automotive sector, operate in rapidly changing environments where the rate of innovation and speed of NPD is crucial (Chen *et al.*, 2010). Therefore, technical knowledge must be shared and transferred among product development teams in a timely manner. Thus:

H6: *KMS response time is positively related to knowledge sourcing*

Flexibility refers to the capability of the system to adapt to different information needs and evolving conditions (Nelson *et al.*, 2005). Flexibility indicates the extent to which a system can be used for different purposes. For example, in an automotive R&D centre, a flexible system implies that users can perform different activities through it such as vehicle modelling, vehicle testing, competitors benchmarking, people-to-people interactions and the like. Moreover, a flexible knowledge repository may also be used to develop transversal knowledge on projects, or to get norms for vehicle development, for example, in order to reflect the latest rules on safety. Therefore, whether the system can be used for performing tasks that satisfy different needs may ease and accelerate KS. Thus:

H7: *KMS flexibility is positively related to knowledge sourcing*

Integration refers to the degree to which a system integrates the knowledge developed in other business units to enable effective decisions. For example, in the context of irregularity management, a KMS may integrate different knowledge developed in different business units like vehicle development, motor propulsion or ergonomics. Moreover, a system can integrate both internal knowledge from different departments and units, and also external knowledge, from other suppliers and customers. Integration is a task-related property (Nelson *et al.*, 2005), and the higher the task complexity, the higher the need for integration. The virtual building of a vehicle prototype is a very complex process, in which different business units collaborate to create and virtually integrate the different parts of a vehicle. The capacity of a KMS to integrate the knowledge produced and archived into different applications might facilitate and accelerate the sourcing of that knowledge for people working in the different units of the organisation. Therefore:

H8: *KMS integration is positively related to knowledge sourcing*

4 Method

Context of the study

This research focuses on the automotive sector because it is a typical example of a knowledge-intensive industry (Jordan and Jones, 1997). Such an industry is characterised by a high pace of change and requires substantial investments in technological knowledge creation and reuse for the development of new products (Jordan and Jones, 1997).

The R&D centre of a large European automotive company was selected for our study. The R&D centre is among the most important automotive private research centers in Europe and employs approximately 1,200 staff and specialises in product prototyping and testing. The centre is provided with sophisticated tools for computer-aided design and calculation and with advanced physical and virtual testing equipment that support the virtual building of a vehicle prototype.

The center has a knowledge repository, which has been recently customised for users' needs to support knowledge sourcing and reuse in the virtual vehicle prototype building. The R&D centre adopts an in-house knowledge repository named 'KMAN' where employees archive and share knowledge during the product prototyping process. The repository is used by R&D people to archive and retrieve different types of knowledge such as knowledge on previous projects, vehicle components, strategies for solving anomalies, and so forth. The knowledge repository used in this company has been recently improved through the adoption of domain (vehicle) ontologies that have been created by the people most active in knowledge sharing. These people have formed an inter-unit community of practice to restructure/refine documents and develop domain ontology. Domain ontology is a set of terms, relations between terms, and inference rules for a topic (domain) that provides the structure, the terminology, and the relationships between knowledge (Liebowitz, 1999). The ontology-based KMS allows for syntactic browsing, where matches are obtained through keyword search; and semantic browsing, where matches are achieved through metadata based on domain ontology. In the issue management process, which is the process through which systems and subsystems of a vehicle are analysed in order to check the presence of potential irregularities, R&D people can retrieve knowledge to solve current problems.

We have selected the case study method because the phenomenon under investigation is new, it is hard to find similar research, and the study attempts to increase researchers' understanding of such phenomenon (Yin, 2003). According to Yin (2003), case studies can be descriptive, exploratory, and explanatory. Our case study is explanatory, since it adopts the DeLone and McLean's (1992) theoretical model to explain the capacity of a knowledge repository to enhance knowledge sourcing and reuse in the context of virtual product prototyping. This NPD stage has been selected because case study research can be based on qualitative and quantitative data collection (Yin, 2003). The quantitative method was preferred because the majority of constructs and items used in this research have been created and tested in previous studies (Nelson *et al.*, 2005). Following an integrated single case study approach (Yin, 2003); three business units (Bus) formed the context for this study. They were selected for their strategic role in the product prototyping process.

Measures and Data Collection

The majority of the items used in this study have been previously used by other researchers to measure the constructs under investigation, with wording modified for the study of knowledge and the knowledge repository. A questionnaire containing all the constructs was formulated and tested within the R&D centre. Prior to the administration of the questionnaire, we have pilot-tested it with R&D engineers and designers directly involved with product prototyping. This preliminary activity helped us to better understand the vehicle prototyping process, to identify ambiguous or poorly worded items, and to test the knowledge sourcing scale. Moreover, these discussions helped us to learn the firm-specific terminology and processes, which were also used in the questionnaire to reduce the cognitive load on respondents. Therefore, questions were explained with references to the specific process of irregularity solution in the VPPD process. After the pilot test, some items were reworded, modified or deleted.

Knowledge quality and systems quality were assessed with items adapted respectively from the work of Wu and Wang (2006) and Nelson *et al.* (2005). The dimensions of knowledge quality included knowledge accuracy, knowledge completeness, knowledge format, and knowledge currency. The dimensions for system quality included system integration, reliability, response time, and flexibility (Nelson *et al.*, 2005). Thus, we have excluded systems' accessibility, since the items used to measure this construct could be confused with knowledge sourcing.

Knowledge reuse was measured through frequency and ease of reuse (Watson and Hewett, 2006). Similarly, the knowledge sourcing effectiveness scale asked respondents to state whether the sourcing of knowledge from the knowledge repository was easy and rapid.

A 5-point Likert scale was adopted to graduate the items, which ranged from strongly disagree to strongly agree. The questionnaire was either administered via e-mail or in person via hard copy. The questionnaire was preceded by an e-mail from the head of each of the three business units involved, with the aim of explaining the nature and goals of the study. To elicit honest answers from the respondents, the head of department assured them that the study was undertaken with the aim of improving business processes and the knowledge repository. In addition, anonymous responses were guaranteed through the nomination of an external individual responsible for questionnaire collection.

Sample

The questionnaire was distributed by email to R&D people within the company and after a period of two months, 158 questionnaires were returned. Of these, 35 were excluded because they were incomplete, accounting for a total number of 121 usable questionnaires. The sample consisted entirely of KMS users and was representative of workers in the R&D centre. Moreover, there was a high percentage of respondents with a high-level of education, 49% of them have a post-graduate diploma (see Table 1). Nevertheless, there were also a significant percentage of people with a low degree diploma (high-school), which constituted 24% of the sample. The majority of respondents were men, aged between 36 to 45 years, who have been working in this R&D centre for between at least five and over 15 years.

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5 Results

Reliability, convergent and discriminant validity tests

The measurement model was then assessed for composite reliability, convergent, and discriminant validity. Composite reliability has been measured for each construct through Cronbach's α, which is the most commonly used composite reliability measure of question items by researchers (Nunnally, 1994). According to Nunnally (1994) a value of 0.70 and over indicates good items' reliability. The Cronbach alpha for most if the items and scales used in this analysis surpassed the value of 0.7; however, for some scales the Cronbach alpha indicated a threshold under the accepted cutoff of $\alpha = 0.7$ (see Table 2) (Bagozzi and Yi, 1988). However, Nunnally (1994) and Cortina (1993) suggest that values above the minimum value of 0.5 can be considered acceptable depending on the number of items per construct. Accordingly, a high number of indicators have generally a positive influence on the reliability coefficients (Cortina, 1993, p.101), and values of 0.5 and 0.6 for constructs with two or three indicators, respectively, do not seem unacceptable (Nunnally, 1994).

We then assessed the convergent and discriminant validity of items through factor loadings and Average Variance Extracted (AVE) (Fornell and Larcker, 1981). As illustrated in Table 3, all items' coefficients exceeded the level of 0.5 (Fornell and Larcker, 1981).

The Variance Inflation Factors (VIFs) method was then used to assess multicollinearity, which assesses interaction effects. VIFs are akin to a ratio of the strength of the signal relative to noise in regression models; Hair *et al.* (2010) recommend using a cut-off of 10 for VIFs, where VIFs ≤10 indicates a low multicollinearity and those >10 might be indicative of high multicollinearity. Some researchers recommended using a much more conservative cut-off of 5 instead of 10 (Hair *et al.*, 2010). All of the regression coefficients had VIFs below the 5 threshold, implying that no multicolinearity exist among the constructs used (the highest VIF was 1.553).

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Assessment of the hypothesised relationships

Results from the regression analysis of the first causal model are reported in table 4 and show that knowledge accuracy is the strongest predictor of knowledge reuse ($\beta = .582$, $p < 0.001$). Other predictors are knowledge completeness ($\beta = .234$, $p < 0.001$), and knowledge format ($\beta = .231$, $p < 0.001$), while knowledge currency has a very low predicting power ($\beta = .116$, $p < 0.05$). Therefore, hypotheses 1, 2, and 4 are validated, while hypothesis 3 is not. This model explains 70% of variance (Adj. $R^2 = .705$).

In the second causal relationship (system quality and knowledge sourcing, see table 4), the strongest predictor of knowledge sourcing is system integration ($\beta = .358$, $p <0.001$). The strength of the relationship between flexibility ($\beta = .311$, $p <0.001$), and knowledge sourcing is quite similar in magnitude and highly significant. Response time ($\beta = .199$, $p <0.05$) is a significant predictor of knowledge sourcing but it has a lower predicting power compared to the previous variables included in the model. Finally, system reliability had the lowest predicting power of knowledge sourcing ($\beta = .125$, $p < 0.05$). In sum, hypotheses 5, 6, 7, 8 are validated. This model explains 32.7% of variance (Adj. R^2 = .327).

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6 Discussion

This study has investigated the antecedents of knowledge sourcing and reuse from an electronic repository by focusing on the VPPD in a large European automotive company, by extending the knowledge base which addresses how KMS are used in this industry. The results of this study emphasise that the reuse of knowledge archived into a knowledge repository depends on different knowledge quality dimensions. Among the predictors of knowledge quality, *knowledge accuracy* was identified as the strongest determinant of knowledge reuse. Previous management studies at an inter-personal level found knowledge ambiguity as a strong barrier to knowledge sharing (Lippman and Rumelt, 1982; Szulanski, 1996; Szulanski, 2000; Szulanski *et al.*, 2004). In this study, we found that a correct and unambiguous codification of knowledge enhances its reuse from a knowledge repository. Accordingly, in the process of anomaly identification and solution, engineers and designers retrieve from the knowledge repository past solutions to solve current and similar anomalies during the VPPD. At this NPD stage, knowledge is particularly complex so it is paramount that R&D workers immediately understand the cause-effect relationships connected with the application of the retrieved knowledge to the current problem they have to solve. This is a *conditio sine qua non* for reusing existing knowledge; thus, the more ambiguous the knowledge, the more difficult it will be to reuse.

The second important antecedent of knowledge quality is *knowledge completeness*. The value added in reusing knowledge is embedded in its comprehensiveness in explaining a phenomenon, or the solution to a problem. For example, in the process of irregularity management, users need to collect different typologies of knowledge such as a description of the irregularity, diagnosis, corrective actions, designs, geometrical information, statistics/mathematics of the model, and the like. Therefore, a user needs to find all this information in a document to be able to reuse it. If the document is complete, R&D workers will not need to extract and aggregate data from different documents and repositories for solving the identified anomaly. If the documents are incomplete, users will have to search for the missing knowledge and information elsewhere, increasing the time needed to solve a problem.

Previous studies have found that the non-meaningful structure of knowledge format was among the reasons for KMS failure (Chua and Lam, 2005) and we agree with such findings as we found that *knowledge format* is another important determinant of KR. For instance, in the process of irregularity management, knowledge can be particularly complex; therefore, a shared and consistent template for codifying and representing knowledge facilitates its immediate identification and understanding. R&D people have to develop and share templates to codify solutions to irregularities/anomalies. A standard format for knowledge codification eases the reuse of knowledge, since each element is immediately identifiable in a document. Therefore, by using such forms users will be able to immediately locate the kind of knowledge they are looking for (e.g., component/part of the vehicle involved, the typology of anomaly, the refinement of the irregularity schedule, and the like). Most of the knowledge used in the solution of an anomaly is presented in forms that R&D workers regularly fill out after its solution.

Findings show that *knowledge currency* is not a strong antecedent of knowledge reuse. This result may be explained by the fact that users do often search for historical knowledge such as previous design models for the solution of irregularities during the VPP. Moreover, the pace of change of knowledge for some parts of a vehicle development is not rapid as for example for other products in other sectors such as smartphones and laptop computers. Therefore, past knowledge can be reused even if it is not current.

Turning to system quality, we have already specified that in the automotive R&D centre under investigation, repositories are based on domain ontologies, which help R&D workers to rapidly identify the area of the problem (ergonomics, acoustic, engine and so on) and the right solution to it. Repositories facilitate the sourcing of the multitude of unstructured documents archived into the system (Kang *et al.*, 2003). Thus, previous research has found that the only use of keyword matching may not be efficient for retrieving such document types; on the contrary, in ontology-based searches, the data input is converted into semantic statements, by capturing and classifying the knowledge contained using domain ontology (Dadzie *et al.*, 2009). In these situations a KMS returns knowledge and not documents, and knowledge seekers do not have to spend too much time in manually mining the content of the retrieved document. In our R&D centre an ontology-based repository enables the comparison of analogies between past and new anomalies, favoring a rapid sourcing of the right solution for the problem, and the advancement of the process.

The capacity of the repository to *integrate* knowledge from other applications in use in the different business units is a critical determinant of knowledge sourcing in the VPPD. Previous research has found that the difficulty to capture cross-functional content was among the reasons for KMS failure (Chua and Lam, 2005). However, in high-tech industries where knowledge is more complex, the capacity of a KMS to integrate the knowledge produced in different areas of the company is paramount. In fact, the vehicle prototyping process is a very complex process due to its high fragmentation; namely specialists from different business units apply different knowledge types to assemble the different parts of vehicle, such as knowledge on design, knowledge on engines, and knowledge on information technologies, and the like. This process requires specialised knowledge from different parts of the organisation and sometimes from other parent organisations of the company (e.g., other R&D

centres). The integration of the knowledge created and archived by employees of different units reduces such complexity, since it enables a better understanding of the entire process and how the different parts of a vehicle may fit together. Increasingly, the sharing of inter-functional knowledge facilitates the sourcing of knowledge from different sources and applications. In fact, whether a system integrates distinct knowledge, there will be less recourse to time consuming communications, such as collective meetings and phone calls.

In this study, *system flexibility* shows a strong predicting power of knowledge sourcing. This result is probably due to the fact that the knowledge repository is used by R&D people for other types of use rather than only retrieving knowledge. Therefore, the KMS is not only adopted for tasks related to the sourcing of solutions to anomalies during the virtual design of a vehicle prototype, but also to retrieve other data, knowledge, and information that would enable users to perform different activities. For instance, the repository can provide also information on previous car designs, norms and rules about vehicle safety and carbon dioxide emissions limits, marketing information on competitors, and so forth. Such knowledge and information will enable R&D people to perform different tasks such as concept idea development, competitors benchmarking, market analysis, safety analysis, and the like. Thus, if a system is flexible, people in an organisation will retrieve knowledge more easily and rapidly from it.

In Nelson *et al.*'s (2005) research on data warehousing systems, *response time* was not found to be an important determinant of system quality; however, it is in the present research. A reason of this finding could be that time is a critical factor in the automotive industry. The speed of NPD is considered to be one of the most important indicators of NPD performance (Boston Consulting Group, 2006), and it constitutes the essence of competition in high technology-based industries (Griffin, 1993). Therefore, the more rapid is the access to the right knowledge, the more rapid will be the solution of an irregularity, and by consequent, the speed at which new products are developed.

The results demonstrate that *system reliability* is not a particularly important predictor of KS. This result may be due to the technological advancements of KMS, which have reduced malfunctioning and have enabled the several mechanisms to recover the data. Accordingly, R&D workers are less likely to encounter technical problems in the knowledge sourcing process; therefore they do not consider the reliability of the system to be a critical factor in their work.

Today, in order to compete successfully, automotive companies must shorten the time needed to develop new products in order to quickly adapt to emerging customers' needs. The capability to quickly and effectively design new products that meet market needs is central for succeeding in highly competitive markets (Chen *et al.*, 2010). Through our study, we can infer that the VPPD process can be improved whether automotive companies improve the effectiveness of knowledge sourcing and knowledge reuse through knowledge repositories and knowledge of higher quality. Accordingly, by facilitating the sourcing of past anomalies within previous vehicle design projects, employees can quickly reuse existing solutions to solve current and similar anomalies, by speeding up the whole vehicle development process.

To summarise our results, the higher the quality of the knowledge archived into a knowledge repository, the higher will be its reuse by other R&D workers, while the higher the quality of the knowledge repository the higher will be the sourcing of knowledge from the same repository. If knowledge is of high quality in its intrinsic, contextual, and representational dimension, users from different departments, business units, parent companies will be more likely to reuse the knowledge archived into KMS for the solution of frequent problems. Indeed, the sourcing of knowledge is influenced by system integration, flexibility, and response time.

7 Limitations and Future Research

The present research has some limitations. First, this is a single case study based on the automotive industry, and it is focused on a specific NPD process, the virtual vehicle prototyping process. Any other research should extend the sample and the number of cases and test the model in other settings and focusing on different processes. In particular, the analysis should be improved by a comparative study in another sector in order to get a cross–industry validation of results.

Our analysis focused on quality determinants of knowledge sourcing and knowledge reuse in the context of a knowledge repository. In this study, we have assumed that the success of a knowledge repository can be tested by analysing how these applications foster and improve KM processes. Thus, future research could adopt structural equation modelling and include also system's use and users' satisfaction in the proposed model. Moreover, future research could also analyse the impact of KMS quality on other KM processes.

Additionally, we recommend future research to use structural equation modelling to test the relationship between knowledge sourcing, knowledge reuse and product prototyping speed. Scholars can measure whether the rapidity and easiness in reusing previous knowledge for solving actual problems can contribute to accelerate the vehicle prototyping process.

8. Conclusions

- Drawing from management and IS literature, the primary objective of this research was to increase our understanding of the key determinants of knowledge reuse and knowledge sourcing from an electronic knowledge repository.

- Drawing from the DeLone and McLean's (1992) model, we have built and tested a model that show that some knowledge quality dimensions positively affect knowledge reuse, and the strongest predictors are knowledge accuracy, knowledge format, and knowledge completeness.

- Findings show also that the quality of the KM system has a positive influence on knowledge sourcing, and the strongest predictors are system integration, flexibility, and response time.
- Our analysis was based on the virtual manufacturing of a vehicle prototype in the NPD process and the hypotheses have been tested in a large European automotive company, an industry characterised by high pace of change and by the importance of knowledge as a source of competitive advantage. Thus, the paper also discusses the application of knowledge repositories in this context by providing new directions for future research on knowledge management processes and product prototyping.

References

Alavi M, Leidner D. 2001. Knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS Quarterly* **25**: 117–136.

Bagozzi RP, Yi Y. 1988. On the evaluation of structural equation models. *Journal of the Academy of Marketing Science* **16**: 74-94.

Benbya H, Belbaly NA. 2005. Mechanisms for knowledge management systems effectiveness: an exploratory analysis. *Knowledge and Process Management* **12**: 203-216.

Boston Consulting Group 2006. The world’s most innovative companies. *Bloomberg Business Week Online*, Special Report—Innovation, April 24, 2006.

Chandrasegaran SK. Ramani K. Sriram RD. Horváth I. Bernard A. Harik RF. Gao W. 2013.

The evolution, challenges, and future of knowledge representation in product design systems. *Computer-Aided Design* **45**: 204-228.

Chen J. Damanpour F. Reilly R.R. 2010. Understanding antecedents of new product development speed: a meta-analysis. *Journal of Operations Management* **28**: 17-33.

Chua A. Lam W. 2005. Why KM projects fail: a multi-case analysis. *Journal of Knowledge Management* **9**: 6-17.

Cooper RG. 1990. Stage-gate systems: a new tool for managing new products. *Business Horizons* **May-June:** 44–54.

Cooper RG. 2008. Perspective: The Stage-Gates Idea-to-Launch Process - Update, What's New, and NexGen Systems. *Journal of Product Innovation Management* **25**:213–232.

Corallo A, Laubacher R, Margherita A, Turrisi G. 2009. Enhancing product development through knowledge-based engineering KBE: A case study in the aerospace industry. *Journal of Manufacturing Technology Management*. **20**: 1070-1083.

Cortina JM. 1993. What is coefficient alpha? An examination of theory and applications. *Journal of Applied Psychology*. **78**: 98-104.

Dadzie A-S. *et al.* 2009. Applying semantic web technologies to knowledge sharing in aerospace engineering. *Journal of Intelligent Manufacturing* **20**: 611–623.

Davenport TH, Prusak L. 1998. *Working Knowledge*. Boston, Harvard Business School Press.

Delone WH, McLean ER. 1992. Information systems success: The quest for the dependent variable. *Information Systems Research*. **3**: 60–95.

Dodgson M, Gann DM, Salter A. 2007. In the case of fire, please use the elevator: simulation technology and organization in fire engineering. *Organization Science* **18**: 849–64.

Durcikova A, Fadel KJ, Butler BS, Galletta DF. 2011. Knowledge exploration and exploitation: The impacts of psychological climate and knowledge management system access. *Information Systems Research* **22**: 855-866.

Filieri R, Alguezaui S. (2015). Knowledge sourcing and knowledge reuse in the virtual product prototyping: an exploratory study in a large automotive supplier of R&D. *Expert Systems: the Journal of Knowledge Engineering* **32**: 637-651.

Fornell C, Larcker DF. 1981. Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research* **48**: 39–50.

Grant R. 1996. Toward a knowledge based theory of the firm. *Strategic Management Journal* **17**:109-122.

Gray PH. 2000. The effects of knowledge management systems on emergent teams: towards a research model. *Journal of Strategic Information Systems* **9**: 175-191.

Gray P, Durcikova A. 2006. The role of knowledge repositories in technical support environments: Speed versus learning in user performance. *Journal of Management Information Systems* **22**: 159-190.

Gray PH, Meister DB. 2006. Knowledge sourcing methods. *Information and Management* **43**: 142-156.

Griffin A. 1993. Metrics for measuring product development cycle time. *Journal of Product Innovation Management* **10**: 112-125.

Hair JF. Tatham R. Anderson R.E. and Black W. 2010 *Multivariate Data Analysis,* Prentice Hall, London.

Halloran D. Manchester S. Moriarty J. Riley R. Rohrman J, Skramstad T. 1978. Systems development quality control. *MIS Quarterly* **2**: 1-13.

Jennex ME, Olfman LA. 2008. Model of Knowledge Management Success. In *Current Issues in Knowledge Management* Jennex M.E. (Ed.), pp. 34-52, IGI Global Publishing, Hershey, New York.

Jennex ME, Olfman LA. 2004. Assessing knowledge management success/effectiveness models. *Proceedings of the 37th Hawaii International Conference on System Sciences* 5-8

January 2004, Big Island, HI, USA

Jordan J, Jones P. 1997. Assessing your company's knowledge management style. *Long Range Planning* **30**: 392-98.

Kang I, Park Y, Kim Y. 2003. A framework for designing a workflow-based knowledge map. *Business Process Management Journal* **9**: 281–294.

King W, Marks VP. and Mccoy S. 2002. The most important issues in knowledge management. *Communications of the ACM* **45**: 93-97.

Kogut B, Zander U. 1992. Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science* **3**: 383-397.

Kulkarni UR, Ravindran S, Freeze R. 2007. A knowledge management success model: Theoretical development and empirical validation. *Journal of Management Information Systems* **23**: 309–347.

Lee YW, Strong DM, Kahn BK, Wang RY. 2002. AIMQ: a methodology for information quality assessment. *Information and Management* **40**: 133-146.

Levitt B, March JG. 1988. Organizational learning. *Annual Review of Sociology* **14**: 319-340.

Lai J-Y, Wang CT, Chou C-Y. 2009. How knowledge map fit and personalization affect success of KMS in high-tech firms. *Technovation* **29**: 313–324.

Levin DZ, Cross R. 2004. The strength of weak ties you can trust: The mediating role of trust in effective knowledge transfer. *Management Science* **50**: 1477-1490.

Liebowitz J. 1999. Key ingredients to the success of an organisation's knowledge management strategy. *Knowledge and Process Management* **6**: 37–40.

Lippman SA, Rumelt RP. 1982. Uncertain imitability: An analysis of inter-firm differences in efficiency under competition. *Bell Journal of Economics* **13**: 418–438.

Lu CM, Zheng S, Jin W, Sheng YF, Sun Y. 2011. Template-Based Expression and Reuse of Design Knowledge. *Advanced Materials Research* **328 – 330**: 274-278.

Maier R. 2007. *Knowledge Management Systems. Information and Communication Technologies for Knowledge Management*, Berlin, Springer.

Malhotra Y. 2004. Why knowledge management systems fail? Enablers and constraints of knowledge management in human enterprises In Koenig, M.E.D. and Srikantaiah, T.K., Eds., *Knowledge Management Lessons Learned: What Works and What Doesn't*, American Society for Information Science Monograph Series, pp. 87–112.

Markus L. 2001. Towards a theory of knowledge reuse: Types of knowledge reuse situations and factors in reuse success. *Journal of Management Information Systems* **18**: 57–93.

Owen R, Horváth I. 2002. Towards product-related knowledge asset warehousing in enterprises. In: Proceedings of the Fourth International Symposium on Tools and Methods of Competitive Engineering. pp. 155–170. HUST Press 2002

Nelson RR, Todd PA, Wixom BH. 2005. Antecedents of information and system quality: An empirical examination within the context of data warehousing. *Journal of Management Information Systems* **21**: 199–235.

Nielsen BB, Michailova S. 2007. Knowledge management systems in multinational corporations: Typology and transitional dynamics. *Long Range Planning* **40**: 314-340.

Nunnally J, Bernstein I. 1994. *Psychometric Theory*. New York, McGraw Hill.

Rai A, Lang SS, Welker RB. 2002. Assessing the validity of IS success models: An empirical test and theoretical analysis. *Information Systems Research* **13**: 50–69.

Rao L, Osei-Bryson K-M. 2007. Towards defining dimensions of knowledge systems quality. *Expert Systems with Applications* **33**: 368-378.

Shaw NG. 2002. Capturing the technological dimensions of IT infrastructure change: A model and empirical evidence. *Journal of the AIS* **2**: 1-33.

Sambamurthy V, Subramani M. 2005. Special issue on information technologies and knowledge management. *MIS Quarterly* **29**: 1–7.

Seddon PB. 1997. A respecification and extension of the DeLone and McLean model of IS success. *Information System Research* **8**: 103–108.

Seemann P, Cohen D. 1997. The geography of knowledge: from knowledge maps to the knowledge atlas. *Knowledge and Process Management* **4**: 247-60.

Schindler M, Eppler M. 2003. Harvesting project knowledge: A review of project learning methods and success factors. *International Journal of Project Management* **21**: 219-228.

Simonin BL. 1999. Ambiguity and the process of knowledge transfer in strategic alliances. *Strategic Management Journal* **20**: 595–623.

Szulanski G. 2000. The process of knowledge transfer: A diachronic analysis of stickiness. *Organizational Behavior Human Decision Processes* **82**: 9–27.

Szulanski G, Cappetta R, Jensen RJ. 2004. When and how trustworthiness matters: Knowledge transfer and the moderating effect of causal ambiguity. *Organization Science* **15**: 600-613.

Turner KL, Makhija MV. 2006. The role of organisational controls in managing knowledge. *Academy of Management Review* **31**: 197–217.

Vaccaro A, Brusoni S, Veloso FM. 2011. Virtual design, problem framing, and innovation: An empirical study in the automotive industry. *Journal of Management Studies* **48**: 99-122.

Wand Y, Wang RY. 1996. Anchoring data quality dimensions in ontological foundations. *Communications of the ACM* **39**: 86-95.

Wang RY, Strong DM. 1996. Beyond accuracy: What data quality means to data consumers. *Journal of Management Information Systems* **12**: 5-34.

Watson S, Hewett K. 2006. A multi-theoretical model of knowledge transfer in organizations: Determinants of knowledge contribution and knowledge reuse. *Journal of Management Studies* **43**: 141-173.

Wixom BH, Todd PA. 2005. User acceptance and user satisfaction: Towards a theoretical integration. *Information Systems Research* **16**: 85-102.

Wixom BH, Watson HJ. 2001. An empirical investigation of the factors affecting data warehousing success. *MIS Quarterly* **25**: 17-41.

Wu J-H, Wang Y-M. 2006. Measuring KMS success: A respecification of the DeLone and McLean's model. *Information and Management* **43**: 728–739.

Wu J-H. 2009. A design methodology for form-based knowledge reuse and representation, *Information and Management* **46**: 365–375.

Xu LDC, Wang Z Bi, J. Yu (2012). AutoAssem: an automated assembly planning system for complex products. *IEEE Transactions on Industrial Informatics* **8**: 669–678.

Yang Q, Song B, Lu WF, Zhang Y. 2007. Integrating knowledge maps in design process configurations for concurrently engineered product development. In *Proceedings of the Institution of Mechanical Engineers—Part B—Journal of Engineering Manufacture* **221**: 431-445.

Yin R. 2003 *Case Study Research. Design and Methods*. Third Edition, Sage Publications Inc., Thousand Oaks, CA.